



THE **DARKSIDE** PROJECT

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On behalf of the **DarkSide** Collaboration

Light Detection In Noble Elements - LIDINE 2015 - Conference
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The DarkSide-50 Collaboration

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- 9) Gran Sasso Science Institute, L'Aquila
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- 12) Institute of High Energy Physics, Beijing
- 13) Institute for Nuclear Research, National Academy of Sciences of Ukraine, Kiev
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- 15) National Research Centre Kurchatov Institute, Moscow
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- 17) Physics Department, Università degli Studi and INFN, L'Aquila
- 18) National Research Nuclear University MEPhI, Moscow
- 19) Physics Department, Università degli Studi and INFN, Milano
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- 22) St. Petersburg Nuclear Physics Institute, Gatchina
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- 31) UMassAmherst, Amherst Center for Fundamental Interactions and Physics Department, Amherst
- 32) Physics Department, Virginia Tech, Blacksburg



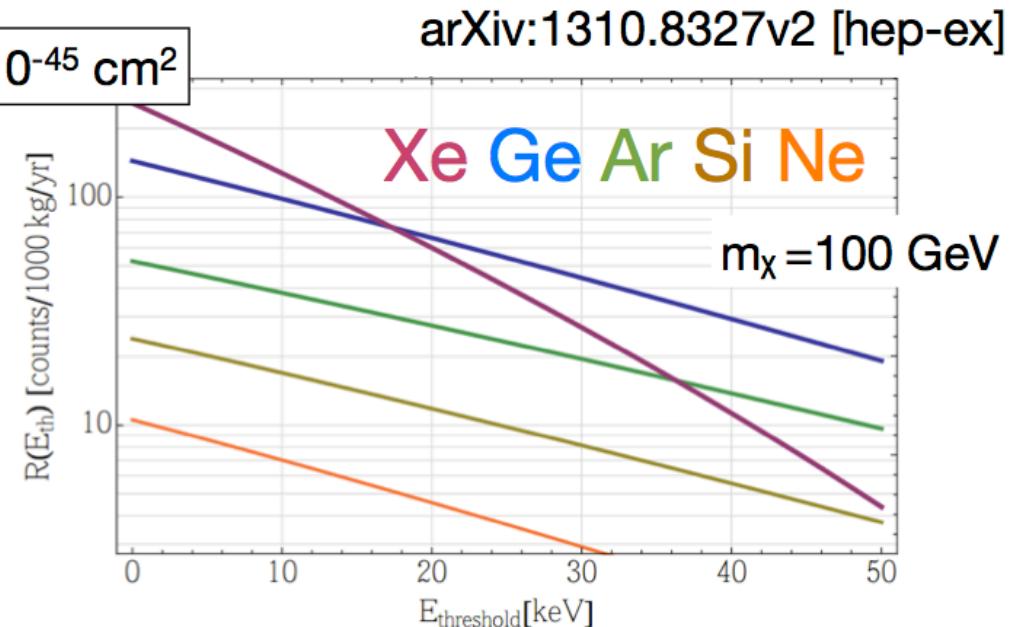
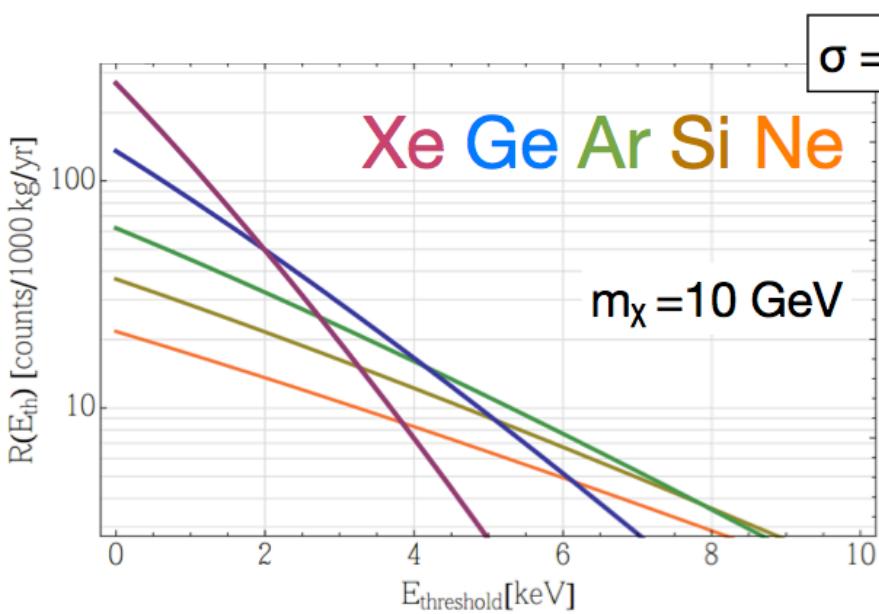
The DarkSide Program

DarkSide is a graded experimental project based on depleted argon

- Direct detection search for WIMP dark matter
- Based on a dual-phase Liquid Argon Time Projection Chamber (LArTPC)
- Ultra low background design
 - Deep underground at LNGS
 - Low-background materials, including Ar target
 - In situ background measurement
- Powerful background rejection
 - Pulse Shape Discrimination (PSD)
 - Ionization/Scintillation ratio (S₂/S₁)
 - Surface rejection using 3D position reconstruction
 - Active neutron and muon vetoes

Liquid Argon as DM detection medium

- Rather high density
 - High insulating power
 - High electron mobility
 - High electron-ion yield
 - High scintillation photons yield (40000 photons/keV)
 - Easy to purify from electro-negative contaminants
 - Abundantly available at reasonably low cost
 - Exceptional discrimination power (PSD and S2/S1 ratio)
 - Scalable technology → very large target mass
- Main drawback: ^{39}Ar (1 Bq/kg)



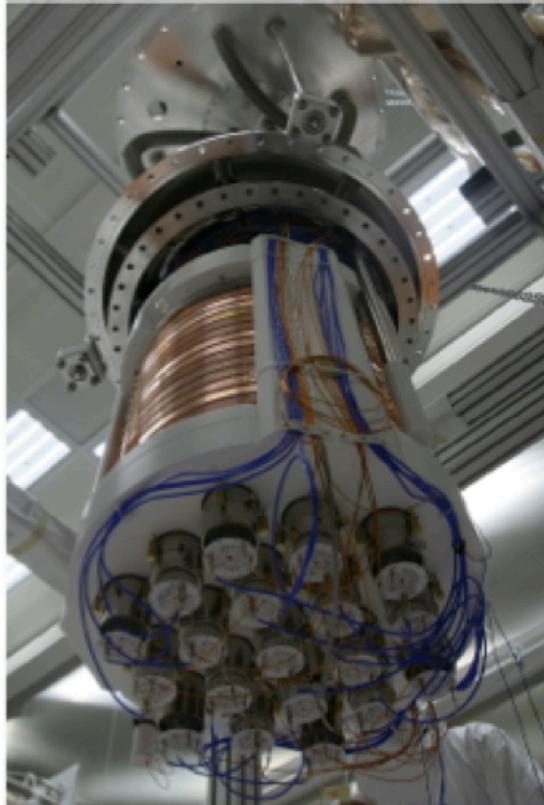
DS timeline: multi-stage approach

DS-10



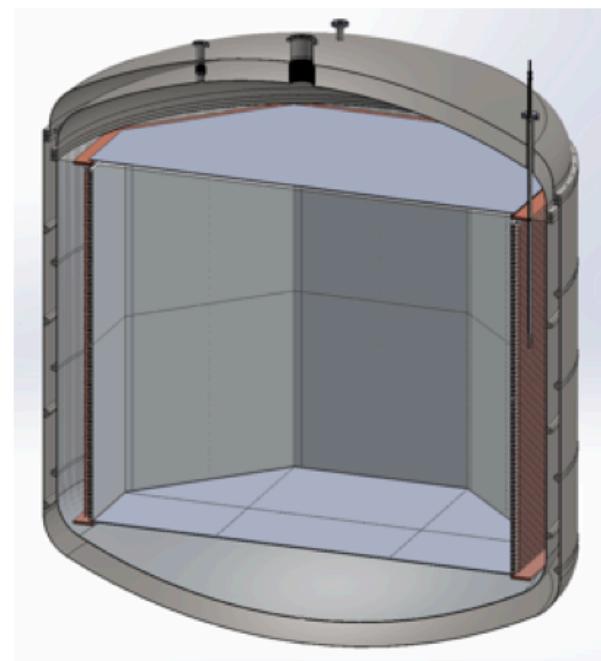
Prototype
(2011)

DS-50



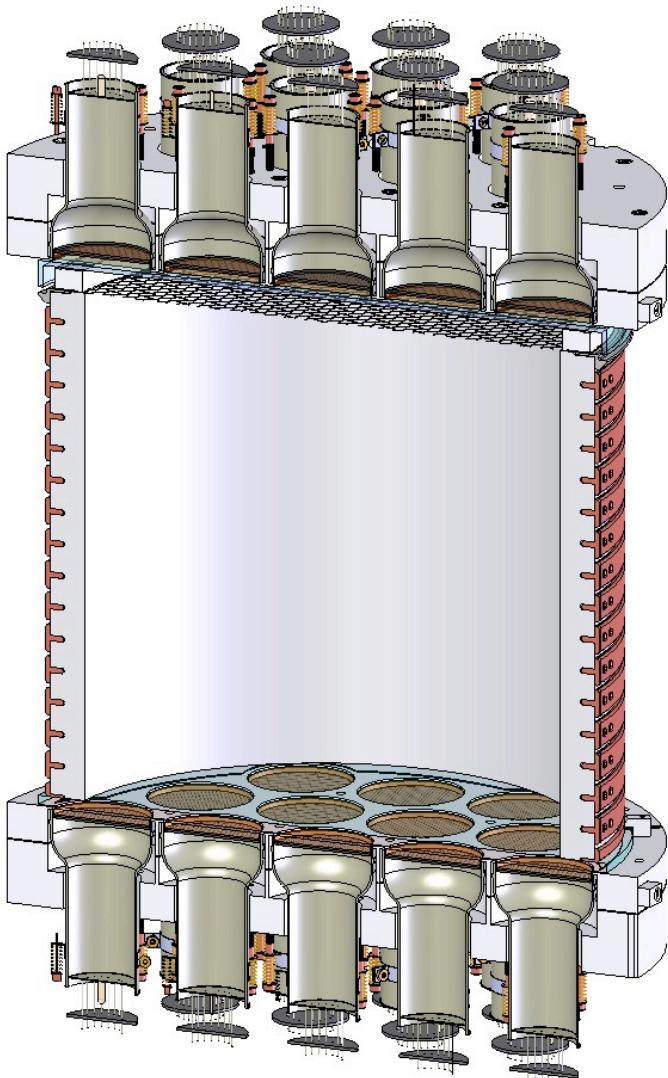
commissioned
October 2013

DS-20k



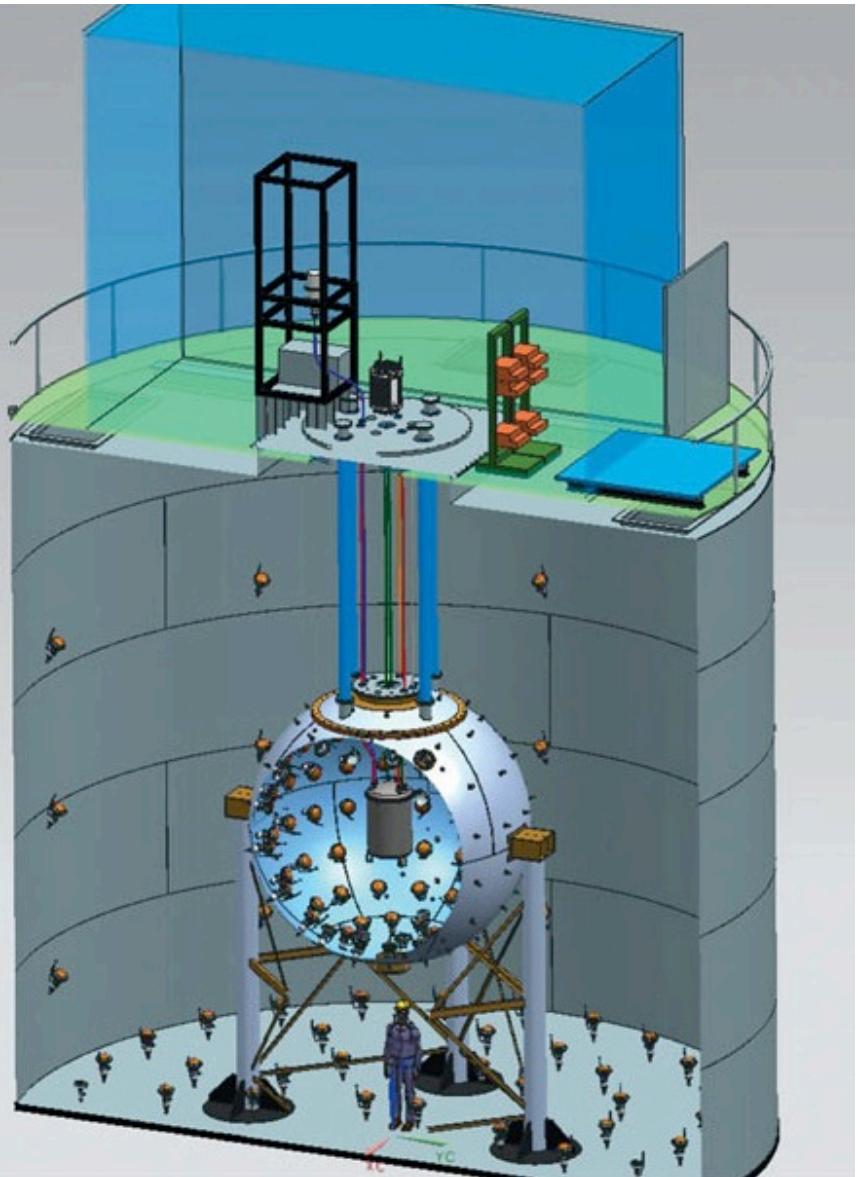
Argo

DarkSide-50 detector: TPC



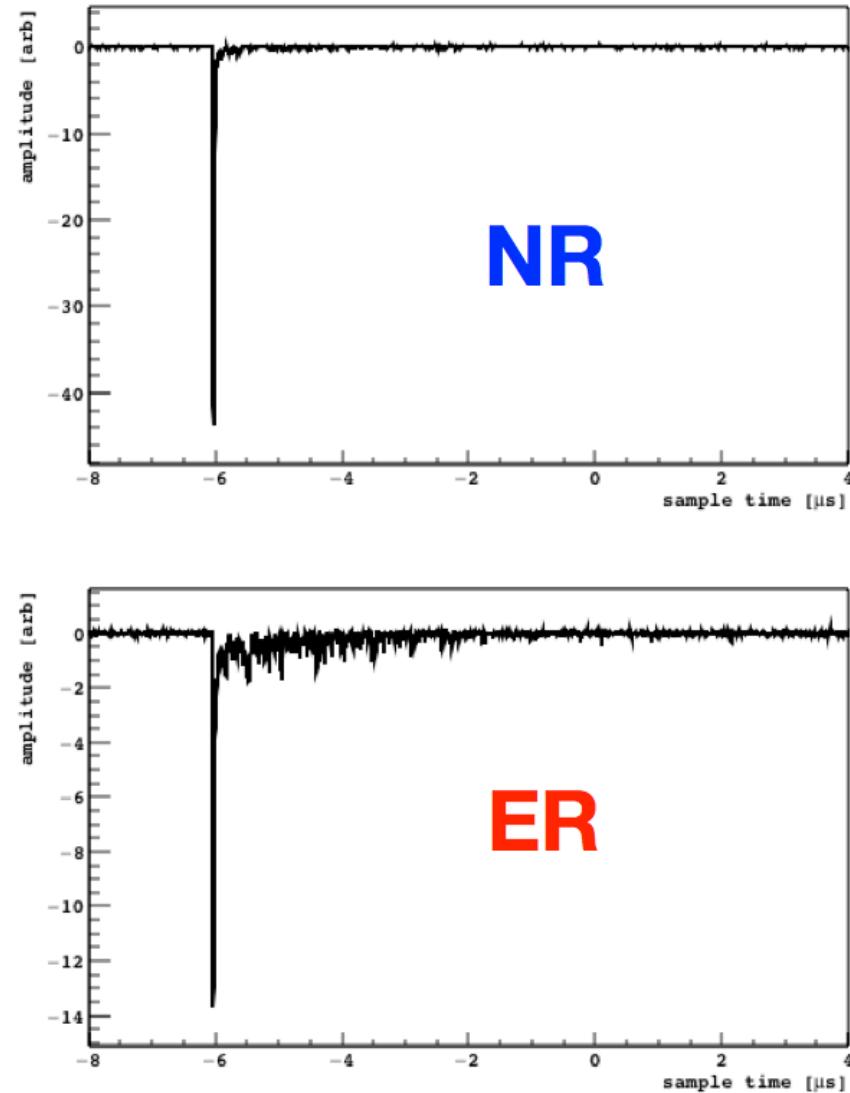
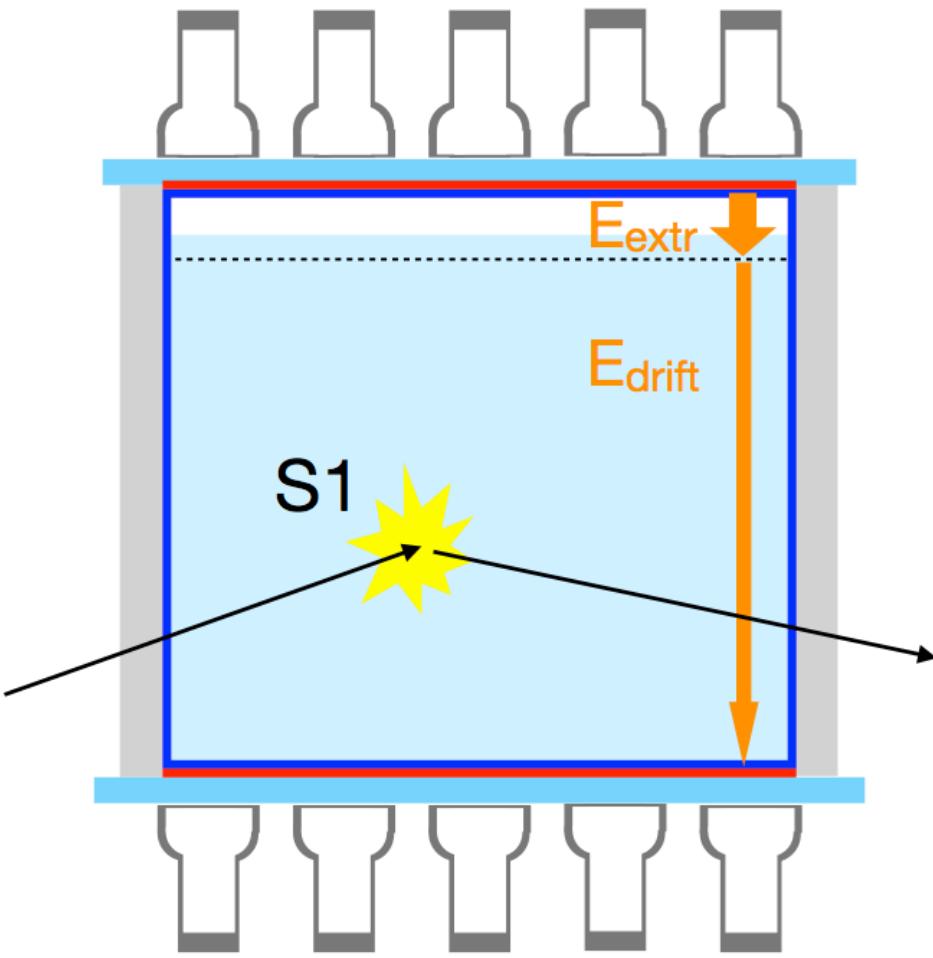
- 46 kg active volume
- 36 cm diameter, 36 cm height
- 38 R11065 3" PMTs
- 38 cold preamplifiers on PMTs
- High reflectivity PTFE walls
- Fused silica anode and cathode windows coated with ITO
- All inner surfaces coated with TPB
- 2 cm gas pocket
- 0.2 kV/cm drift & 2.8 kV/cm extraction electric fields
- Electron drift lifetime > 5 ms (max. drift time of $\sim 375 \mu\text{s}$)
- Electron drift speed = $0.93 \pm 0.01 \text{ mm}/\mu\text{s}$

DarkSide-50 detector: Veto

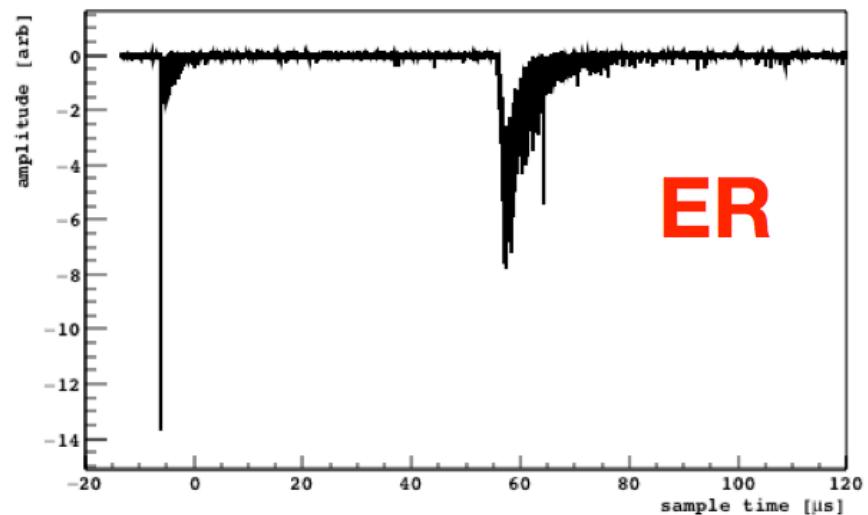
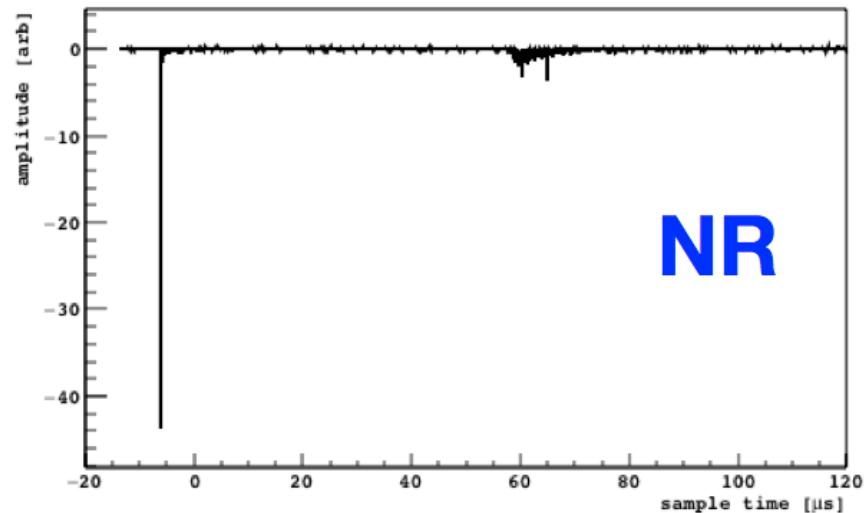
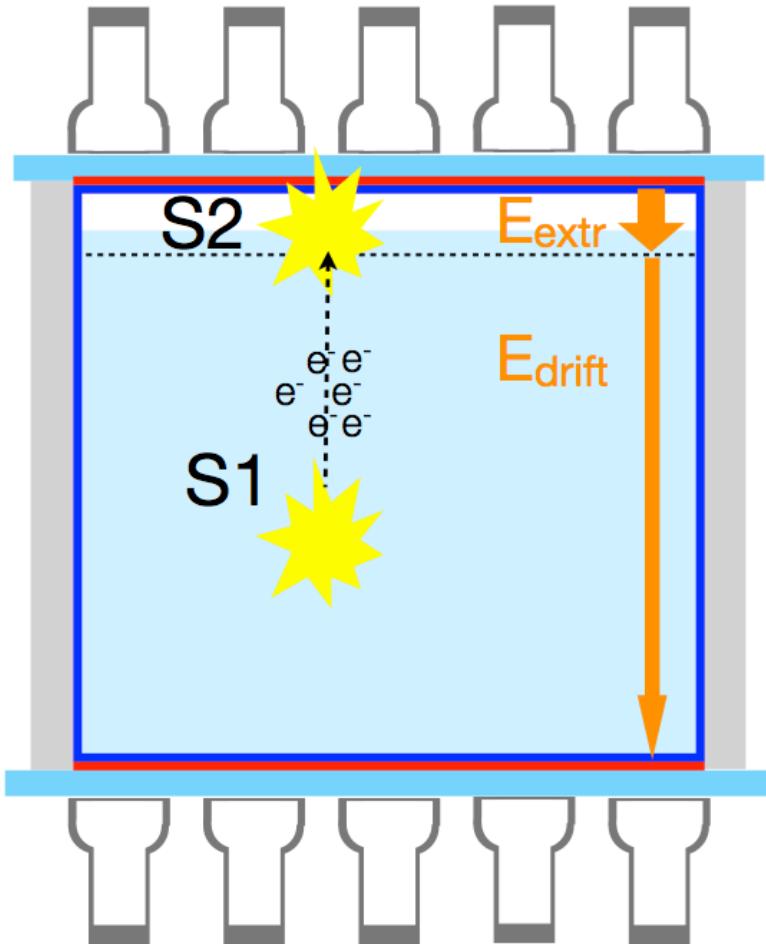


- **Liquid Scintillator Veto**
 - 4 m diameter sphere
 - Boron-loaded: PC + TMB
 - 110 8" PMTs
 - Active neutron veto
 - tag neutrons in TPC
 - in situ measurement of neutron BG
 - Neutron and gamma shielding
- **Water Tank**
 - 11 m diameter x 10 m high
 - Existing Borexino CTF tank
 - 80 PMTs
 - Active muon veto
 - tag cosmogenic neutrons
 - Neutron and gamma shielding

DarkSide-50 TPC working principles: primary scintillation light



DarkSide-50 TPC working principles: secondary electroluminescence light



Pulse shape discrimination in LAr

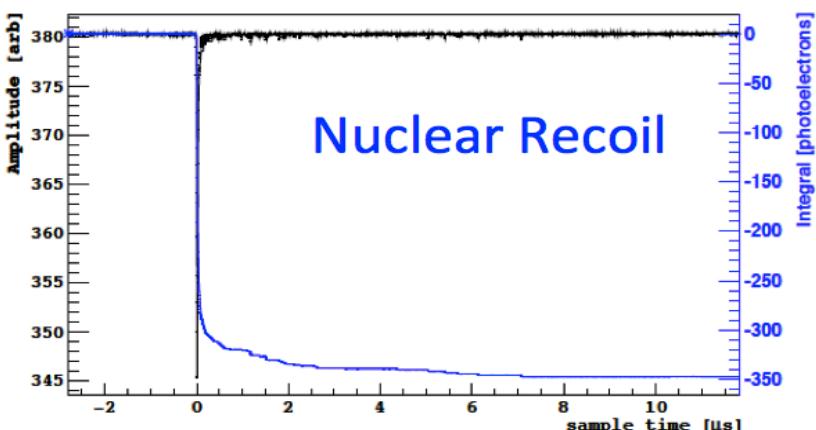
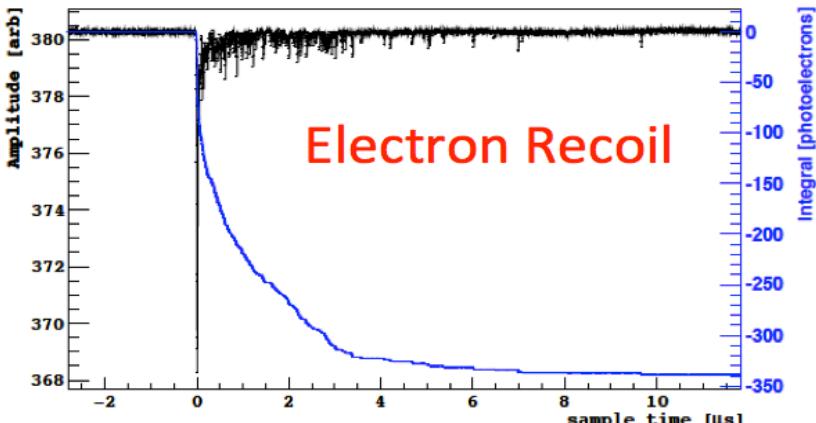
Electron and nuclear recoils produce different excitation/ionization densities in the argon, leading to different ratios of singlet and triplet Ar₂* dimer states:

$$\ell(t) = \frac{A_S}{\tau_S} \exp\left(\frac{-t}{\tau_S}\right) + \frac{A_T}{\tau_T} \exp\left(\frac{-t}{\tau_T}\right)$$

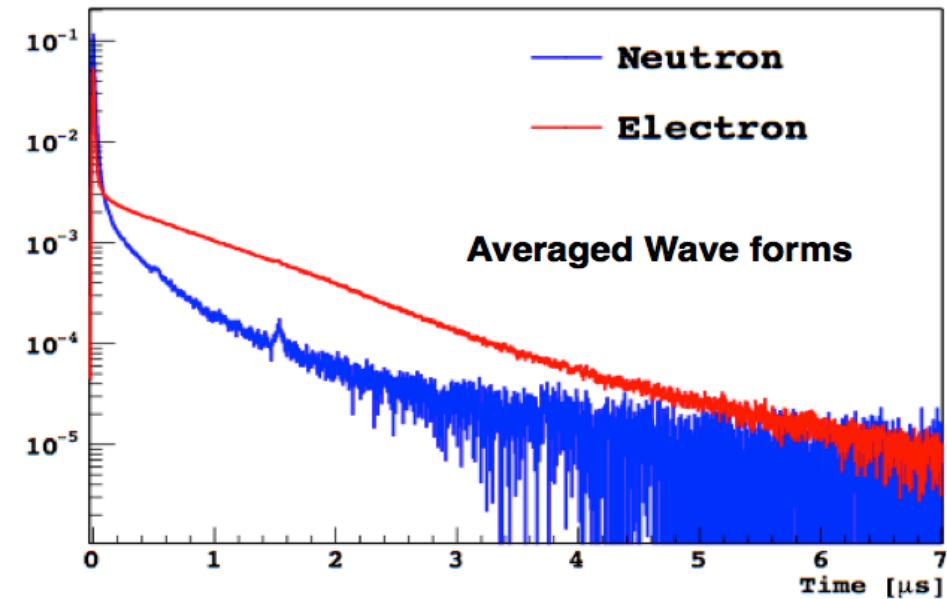
$$\begin{aligned}\tau_S\left(^1\Sigma_U\right) &= 5 \div 7 \text{ ns} \\ \tau_T\left(^3\Sigma_U\right) &= 1300 \div 1600 \text{ ns}\end{aligned}$$

$$\int \ell(t) dt = A_S + A_T = 1$$

The ratio A_S/A_T depends on the ionizing particle



- $A_S/A_T=1/3$ for electron recoils (β and γ interactions)
- $A_S/A_T=3/1$ for nuclear recoils (n and WIMP interactions)



DarkSide-50: Backgrounds

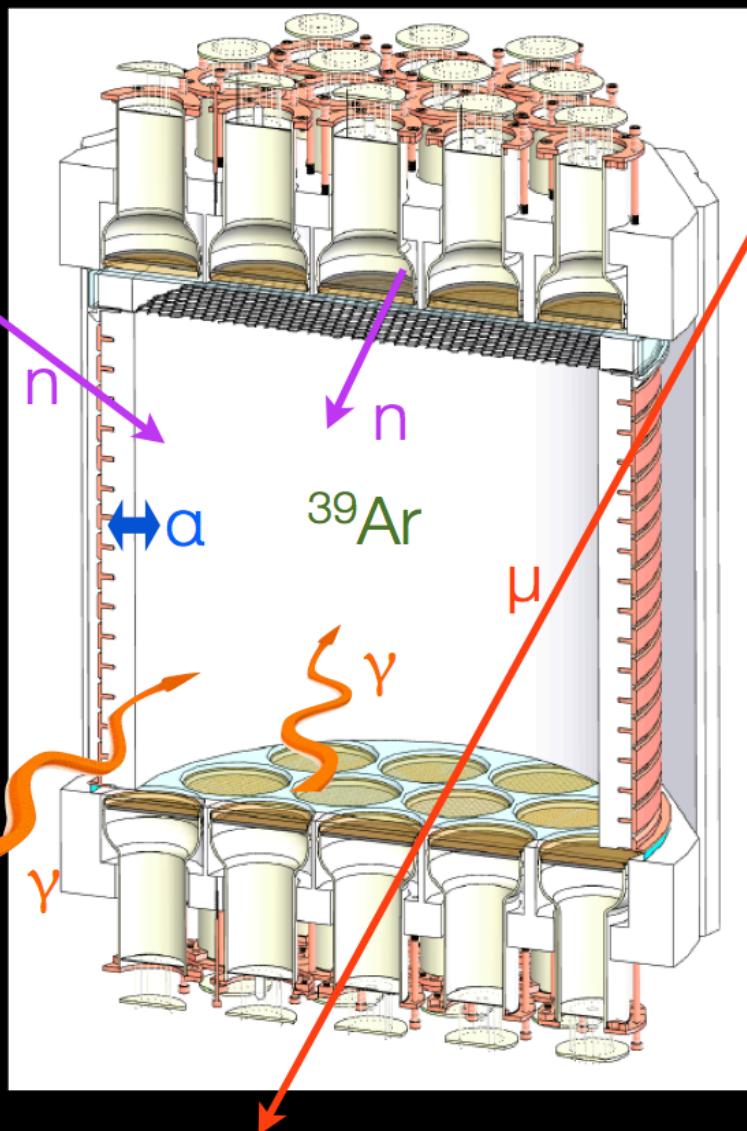
ELECTRON RECOILS

^{39}Ar

$\sim 9 \times 10^4 \text{ evt/kg/day}$

γ

$\sim 1 \times 10^2 \text{ evt/kg/day}$



NUCLEAR RECOILS

μ

$\sim 30 \text{ evt/m}^2/\text{day}$

Radiogenic n

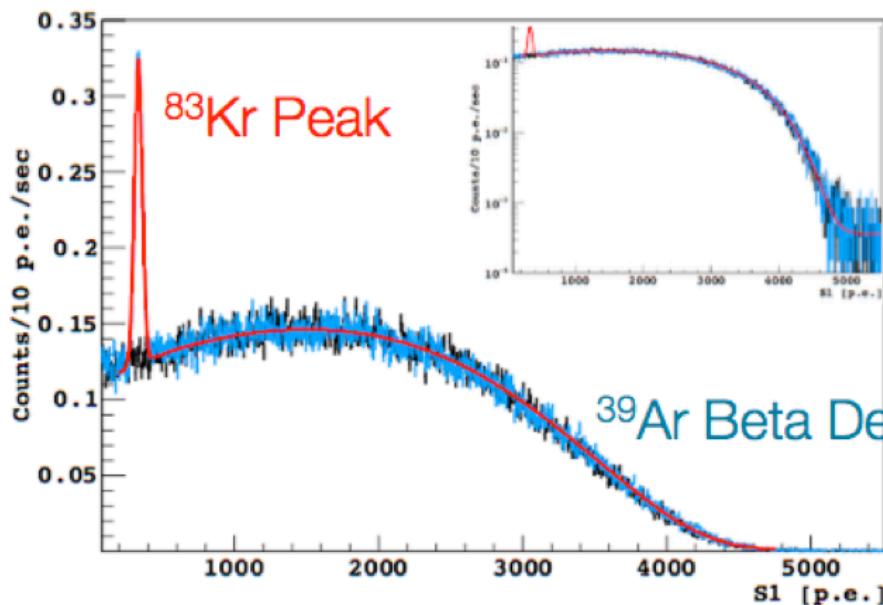
$\sim 6 \times 10^{-4} \text{ evt/kg/day}$

α

$\sim 10 \text{ evt/m}^2/\text{day}$

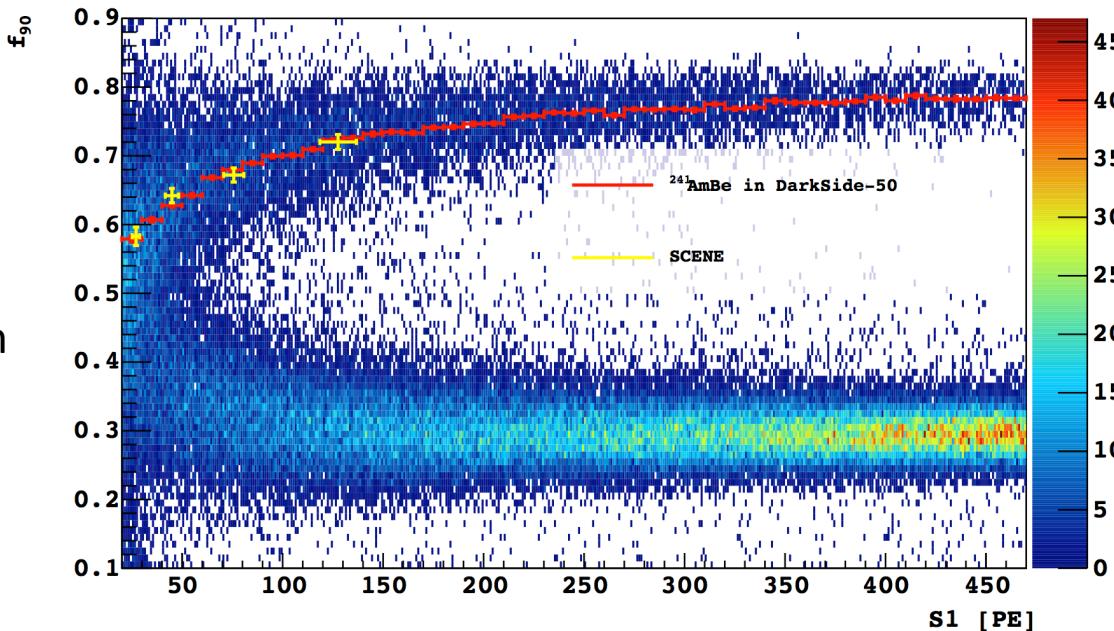
100 GeV, 10^{-45}cm^2 WIMP Rate $\sim 10^{-4} \text{ evt/kg/day}$

DS-50 TPC Calibrations: LY & Neutrons



- TPC filled with atmospheric argon (1 Bq/kg)
- $^{83\text{m}}\text{Kr}$ gas deployed into detector (41.5 keV_{ee})
- Light yield at zero field: (7.9 ± 0.4) phel/keV
- Light yield at 200 V/cm: (7.0 ± 0.3) phel/keV
- Exceeding design requirements of 6.0 phel/keV

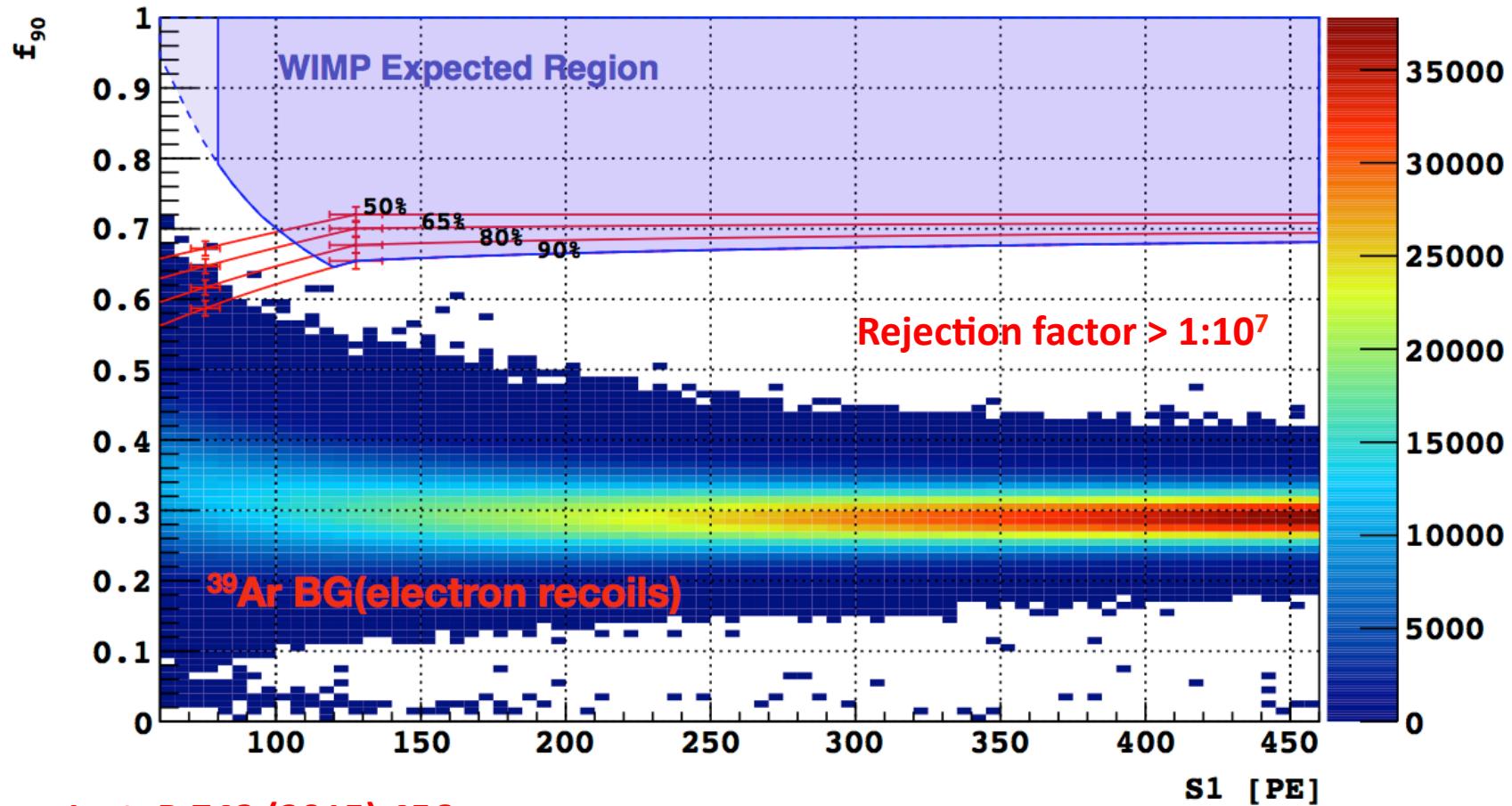
- CALIS deployed Sept 2014
- Calibration campaigns Oct - Dec 2014 & Jan - Feb 2015
- Validate NR band extrapolated from SCENE for first paper
- Tuned MC



DS-50: First Physics Result

Background free exposure of $1422 \pm 67 \text{ kg}\times\text{day}$

No background events in nuclear recoil (WIMP) region!



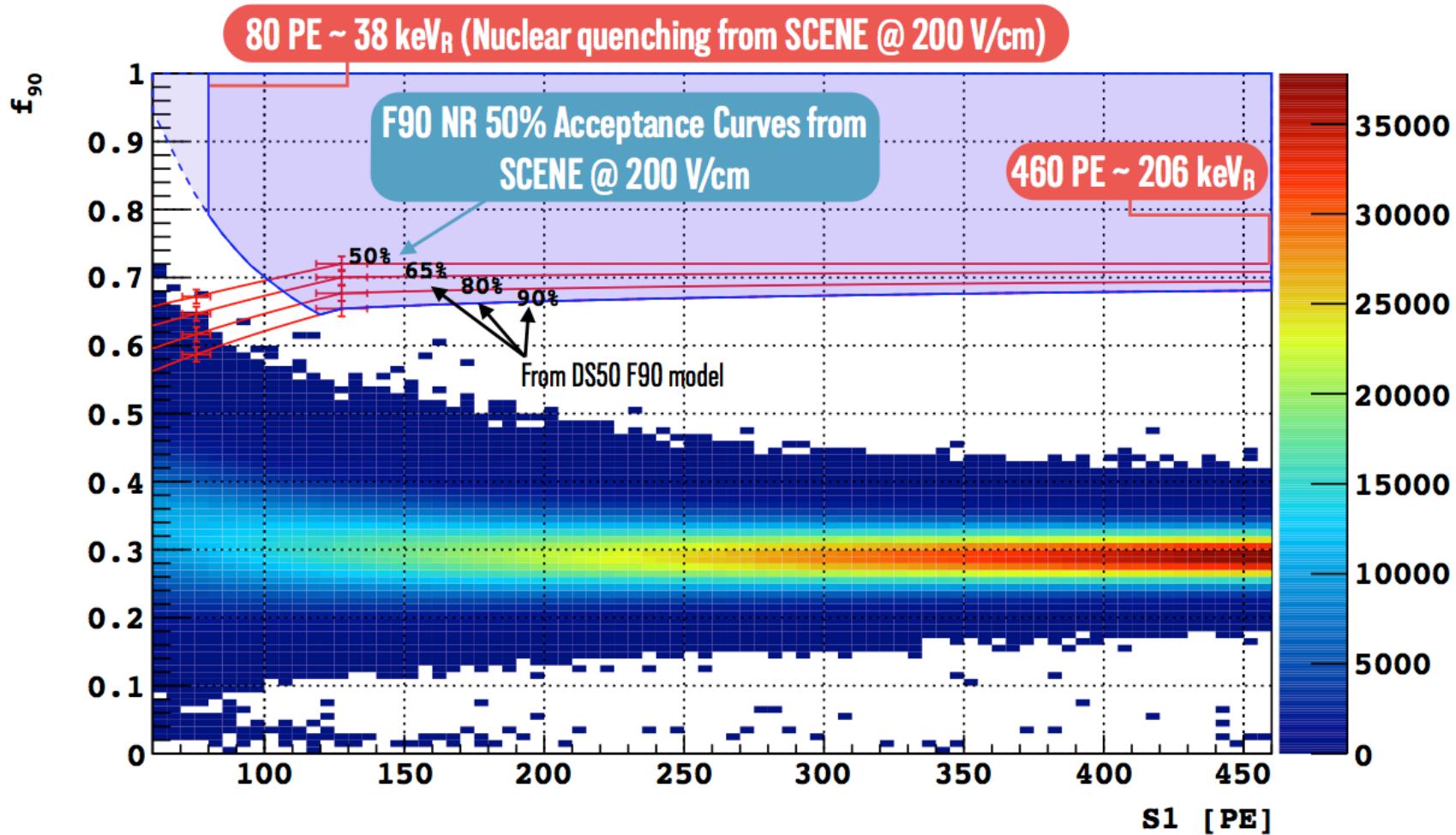
Phys. Lett. B 743 (2015) 456

Corresponds to ≥ 20 yr exposure of DS-50 with UAr

Selected only single-hit interactions in the TPC fiducial volume (36.9 kg) with no energy deposition in the veto

DS-50: First Physics Result

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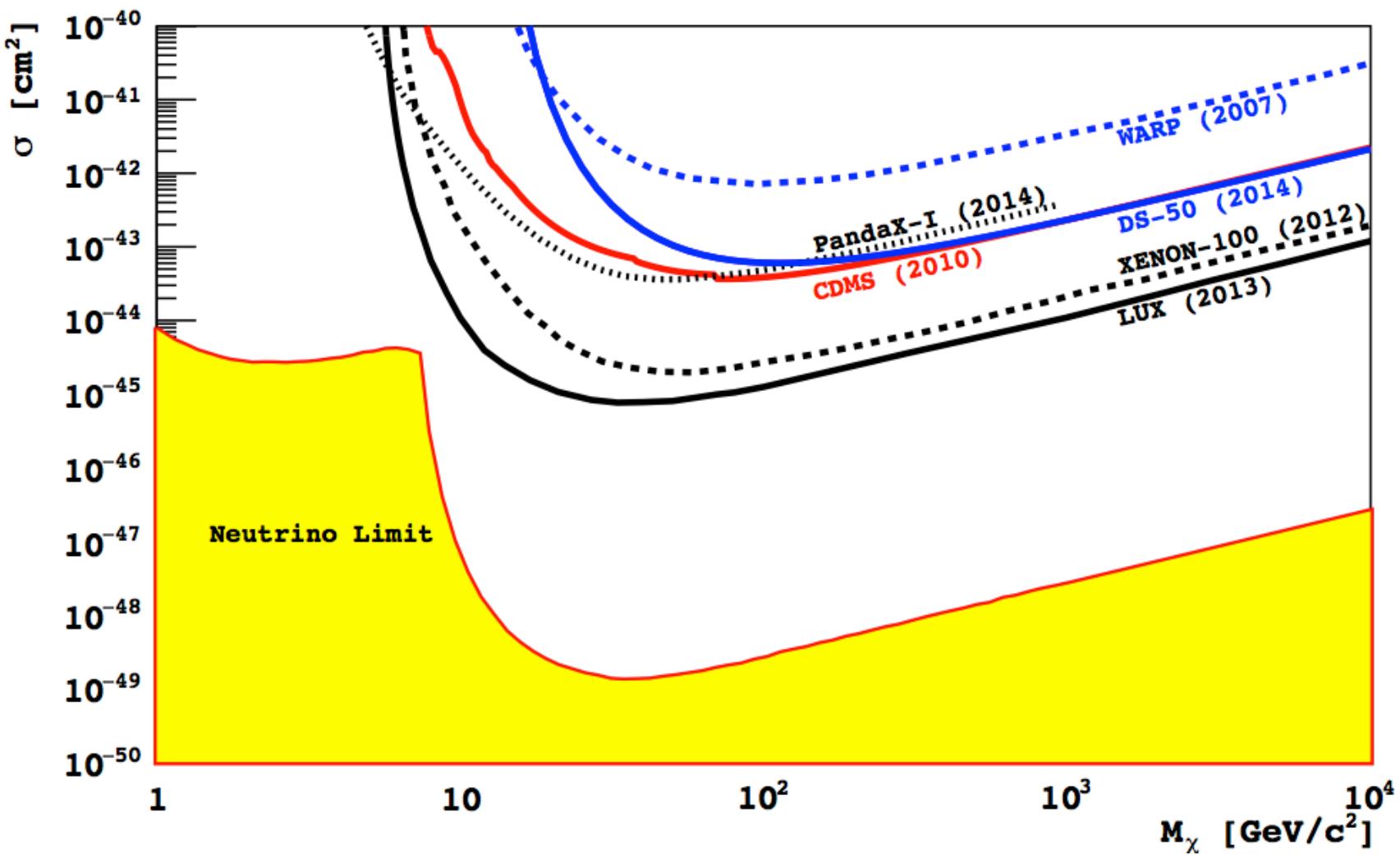
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DS-50: Exclusion Plot

- The most sensitive dark matter search performed with an argon target
- Third best WIMP dark matter limit at high masses
- The WIMP-nucleon spin-independent cross section is $6.1 \times 10^{-44} \text{ cm}^2$ for a $M_W = 100 \text{ GeV}/c^2$



DS-50: Underground Argon

- **Atmospheric argon:**
 - high concentration of ^{39}Ar
 - β -decay (269 yr half life)
 - cosmogenically activated
 - 565 keV endpoint

- **Underground argon:**
 - significantly reduced ^{39}Ar activity
 - allows to scale to large detectors



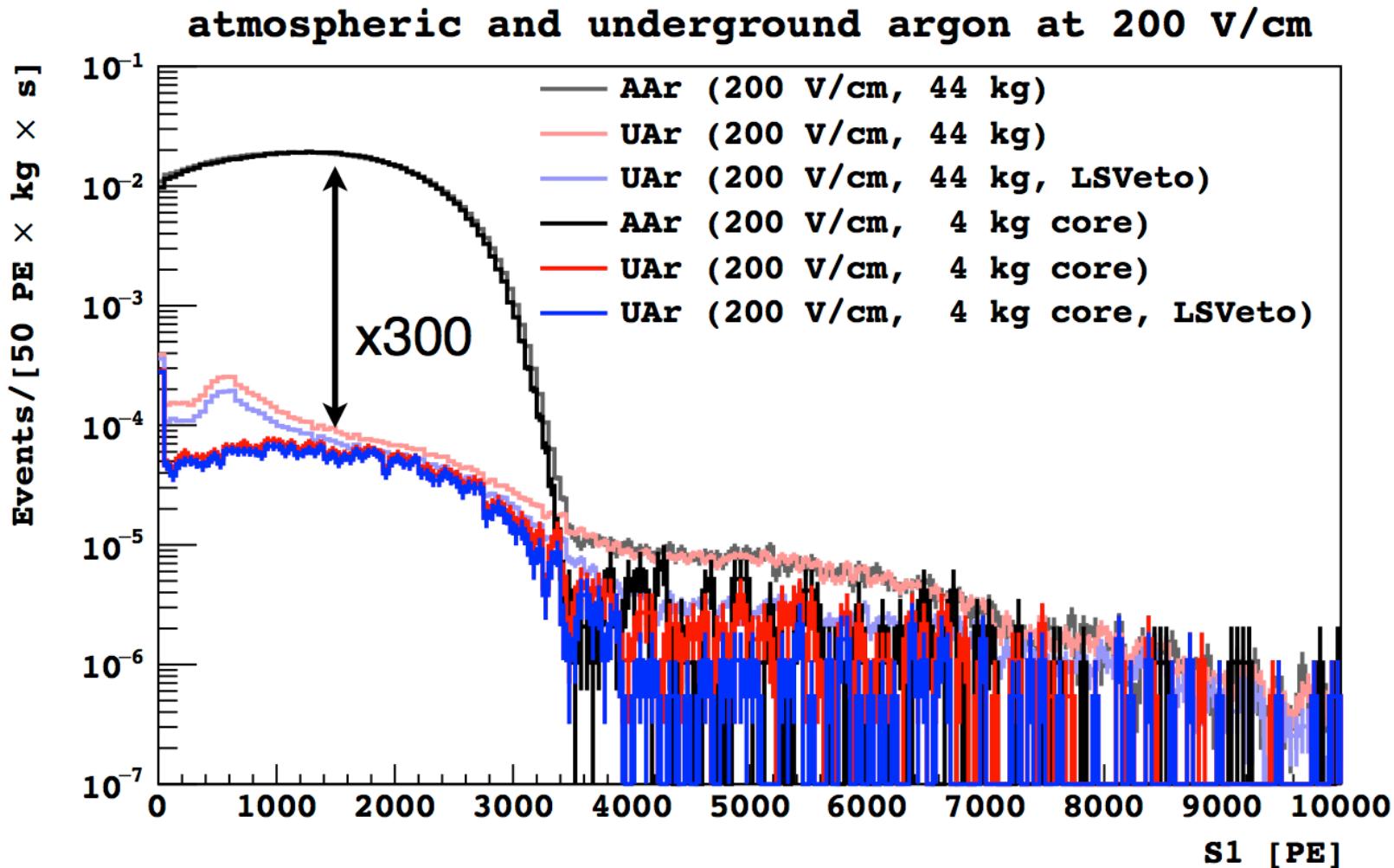
Underground Argon production:

- Extracted in New Mexico
- Distilled in FNAL
- Shipped to LNGS

UAr data taking:

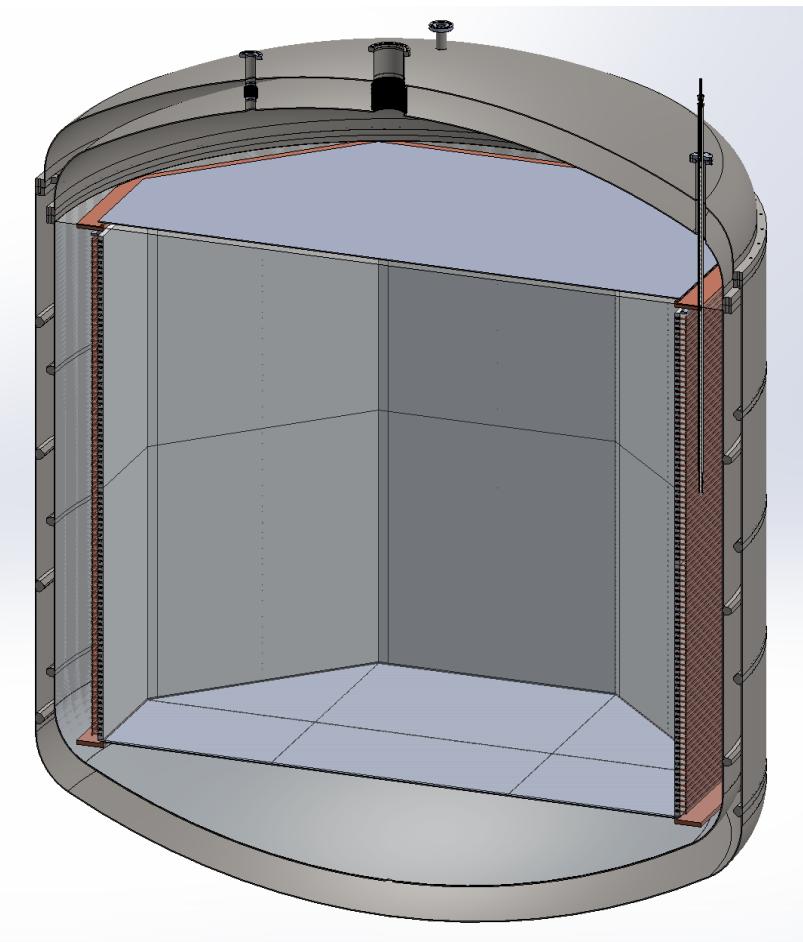
- Started on April 2015
- 1.4 ton \times day already achieved
- New calibrations

DS-50: First UAr Background Result



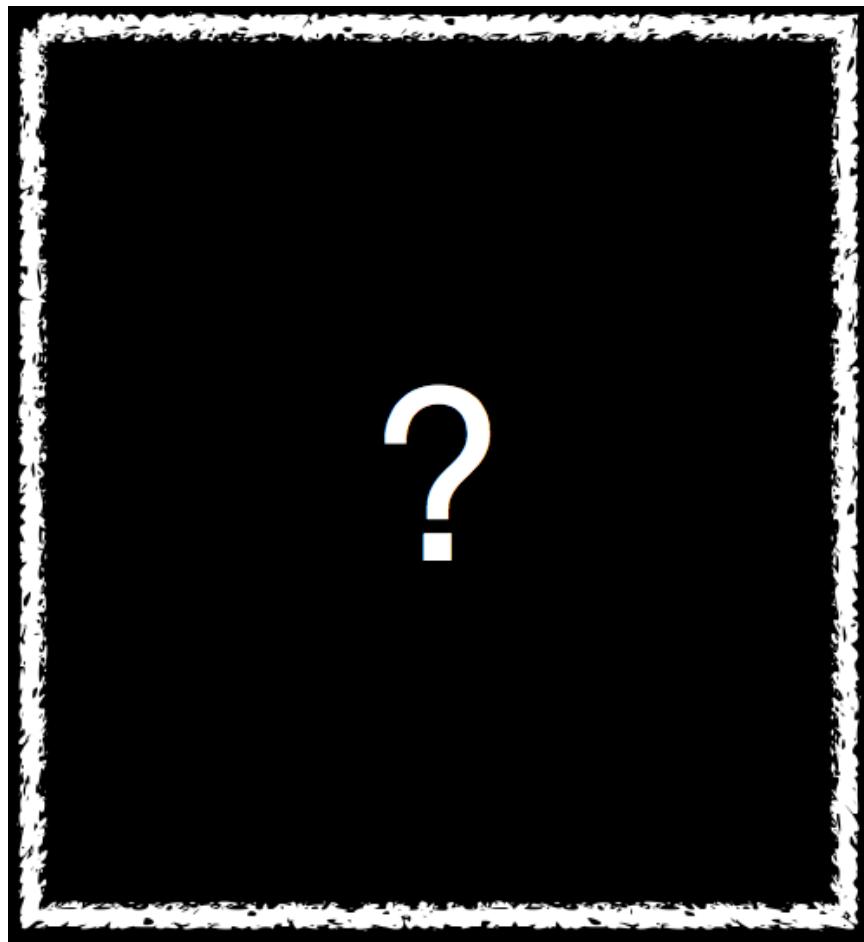
- Concentration of ^{39}Ar in UAr is at least **300** times lower than in AAr
- Low level of ^{39}Ar allows extension of DarkSide program to ton-scale detector

DarkSide Project: Future Plans



DS-20k

30 tons (20 tons fiducial) detector



ARGO

300 tons (200 tons fiducial) detector

DarkSide-20k & Argo Lol Signatories

D. Franco, A Tonazzo (**APC Paris**)

D. Alton (**Augustana**)

A. Kubankin (**Belgorod**)

K. Keeter, B. Mount (**BHSU**)

A. Devoto, M. Lissia, M. Mascia, S. Palmas
(**Cagliari**)

A.A. Machado, E. Segreto (**Campinas**)

M. Leal, L. Romero, R. Santorelli (**CIEMAT**)

S. Horikawa, K. Nikolics, C. Regenfus,
A. Rubbia (**ETH**)
S. Pordes (**Fermilab**)

A. Gola, C. Piemonte (**FBK & TIFPA**)

M. Pallavicini, G. Testera, S. Zavatarelli
(**Genova**)
S. Davini (**GSSI**)

E. Hungerford, A. Renshaw (**Houston**)

M. Guan, J. Liu, Y. Ma, C. Yang, W. Zhong (**IHEP**)

M. Misziazek, K. Pelczar, M. Woicik, G. Zuzel
(**Jagiellonian**)

K. Fomenko, A. Sotnikov, O. Smirnov (**JINR**)
M. Skorokhvatov (**Kurchatov**)

N. Canci, F. Gabriele, G. Bonfini, A. Razeto,
N. Rossi, F. Villante (**LNGS**)

S. De Cecco, C. Giganti (**LPNHE Paris**)

D. D'Angelo, G. Ranucci (**Milano**)

A. Chepurnov, G. Girenok, I. Gribov,
M. Gromov, I. Zilcov (**MSU**)
H. Back (**PNNL**)

M. Ghioni, A. Gulinatti, L. Pellegrini, I. Rech,
A. Tosi, F. Zappa (**PoliMi**)

C. Galbiati, A. Goretti, A. Ianni,
P. Meyers, M. Wada (**Princeton**)

C. Dionisi, S. Giagu, M. Rescigno (**Roma 1**)
S. Bussino, S. Mari (**Roma 3**)

A. Derbin, V. Muratova, D. Semenov,
E. Unzhakov (**St. Petersburg**)

C. Jollet, A. Meregaglia (**Strasbourg**)

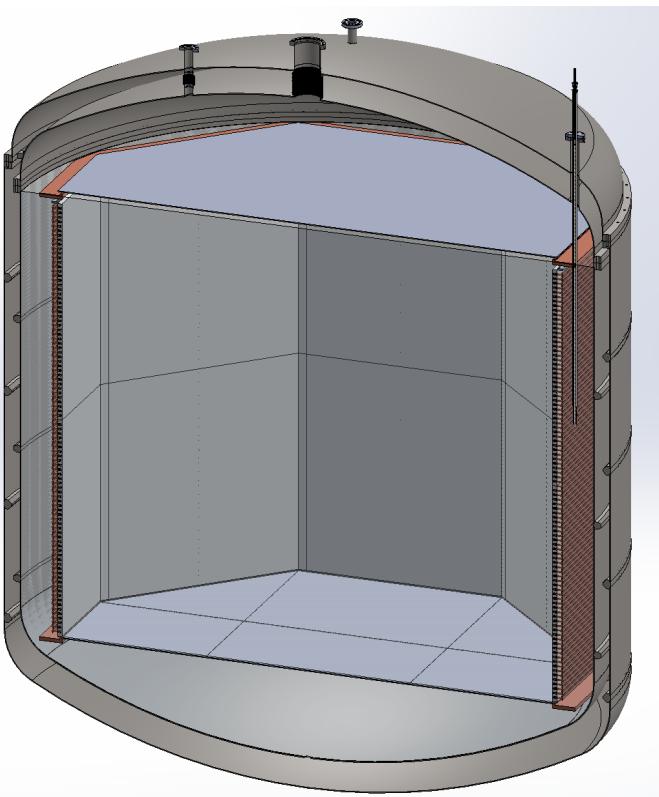
C.J. Martoff, J. Napolitano, J. Wilhelm (**Temple**)
E. Pantic (**UC Davis**)

Y. Suvorov, H. Wang (**UCLA**)
A. Pocar (**UMass Amherst**)

F. Ortica, A. Romani (**Perugia**)
S. Catalanotti, A. Cocco, G. Covone,
G. Fiorillo, B. Rossi (**Napoli**)

J. Maricic, R. Milincic, B. Reinhold (**Hawaii**)
P. Cavalcante (**Virginia Tech**)

DarkSide Project: DS-20k



Main features:

- Based on SiPM's (from 15 to 50% LY increase per unit area over PMT's)
- 30 tons (20 tons fiducial) detector
- MC indicates UAr self-vetoing sufficient (LS veto not required)
- Low-background titanium cryostat

DS Depleted Argon Sources:

Urania project:

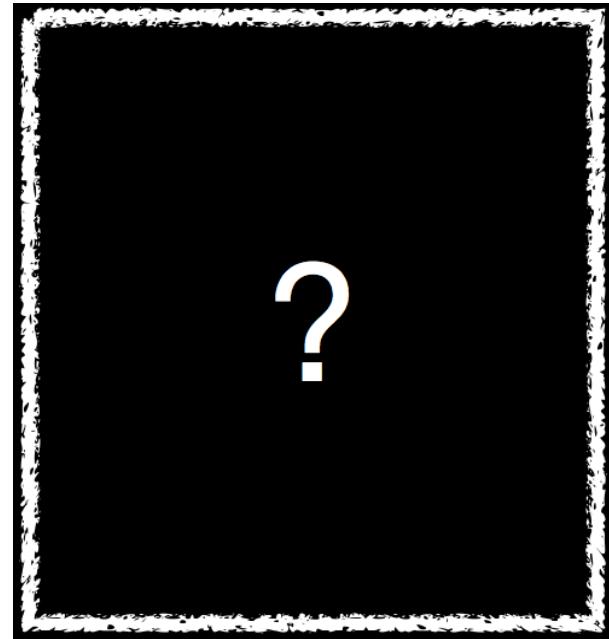
- expansion of Colorado UAr extraction facility to reach up to ~100 kg/day

Aria project:

- Big cryogenic distillation column in Seruci, Sardinia
- Gas purification & active isotopic depletion exploiting finite vapor pressure difference $^{39}\text{Ar}/^{40}\text{Ar}$

DarkSide Project: ARGO

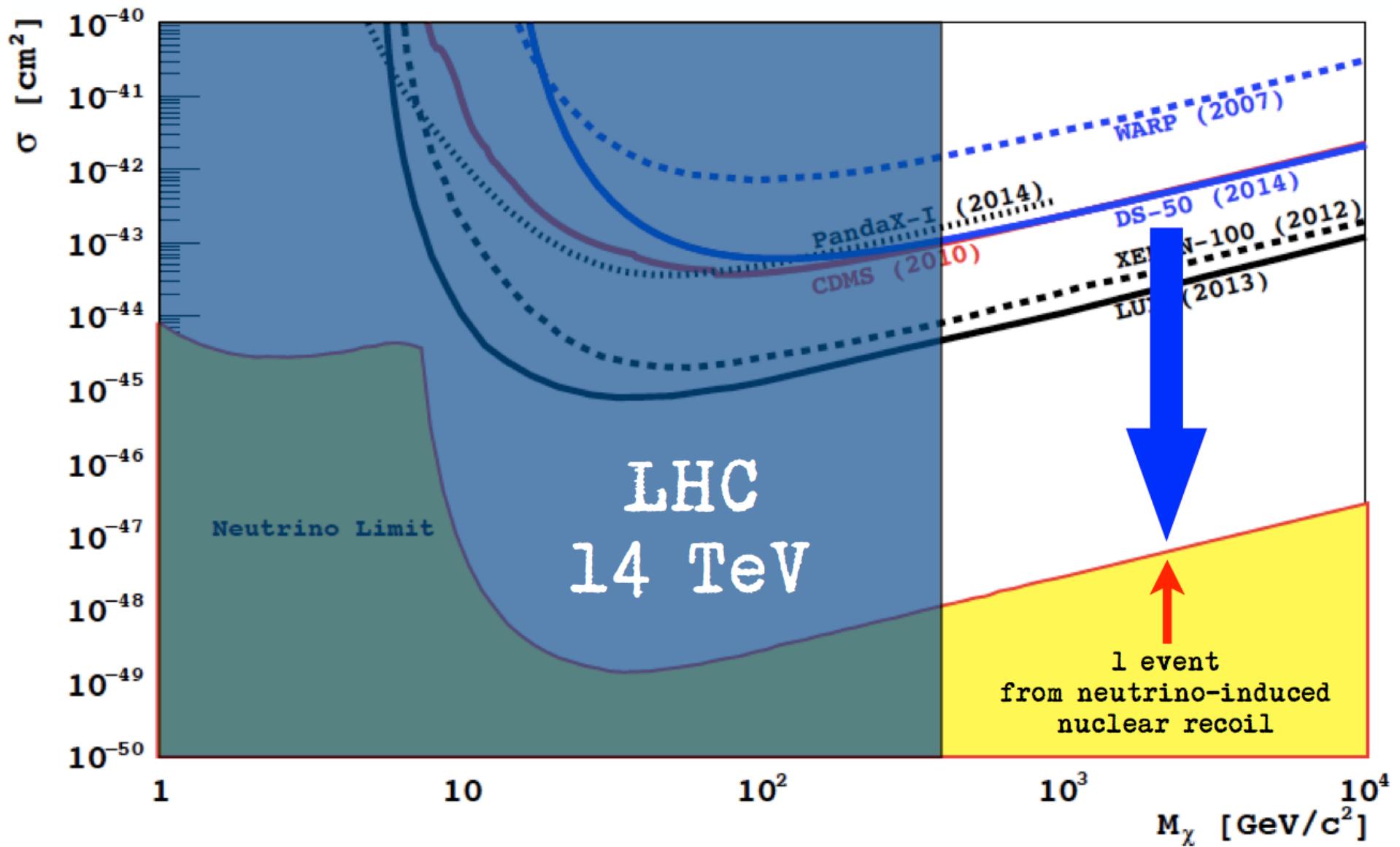
- Background-free exposure of 1000 tons \times yr
- Sensitivity $9 \times 10^{-49} \text{ cm}^2$ @ 1 TeV/cm 2
 - Covers space throughout neutrino floor
- Permits precision measurements of solar neutrinos
 - TPC affords very sharp definition of fiducial volume
 - Argon ten times brighter than organic liquid scintillator
 - Statistical precision 2% for ${}^7\text{Be}$, 10% for *pep*, and 15% for CNO neutrinos
 - Systematics under study
 - Cosmogenics under control
- 300 tons detector
 - Requires Borexino-style shield for solar neutrinos study



DarkSide Project: Physics Goals

Experiment	σ [cm ²] @ 1 TeV/c ²	σ [cm ²] @ 10 TeV/c ²
LUX [10k kg×day Xe]	1.1×10^{-44}	1.2×10^{-43}
XENON [7.6k kg×day Xe]	1.9×10^{-44}	1.9×10^{-43}
DS-50 [1.4k kg×day Ar]	2.3×10^{-43}	2.1×10^{-42}
ArDM [1.5 tonne×yr Ar]	8×10^{-45}	7×10^{-44}
DEAP-3600 [3.0 tonne×yr Ar]	5×10^{-46}	5×10^{-45}
XENON-1ton [2] [2.7 tonne×yr Xe]	3×10^{-46}	3×10^{-45}
LZ [1] [15 tonne×yr Xe]	5×10^{-47}	5×10^{-46}
DS-20k [100 tonne×yr]	9×10^{-48}	9×10^{-47}
1 Neutrino Event [400 tonne×yr Ar or 300 tonne×yr Xe]	2×10^{-48}	2×10^{-47}
ARGO [1,000 tonne×yr]	9×10^{-49}	9×10^{-48}

DarkSide Project: Physics Goals



Conclusions

- ◆ DS-50 is running with UAr at LNGS since Apr 2015 and first UAr physics results coming soon
- ◆ First results published with atmospheric argon in DS-50:
 ^{39}Ar BG from 47.1 live days (1422 kg \times day fiducial) of AAr corresponds to that expected in 38.7 years of UAr DS-50 run (planning physics run time, 3 years)
- ◆ Concentration of ^{39}Ar in UAr is at least 300 times lower than in AAr
- ◆ Ar technology shows good performances for dark matter search, especially thanks to the high rejection power
- ◆ DarkSide-50 AAr & UAr are demonstrating the feasibility of the dark matter detection based on LAr
- ◆ LAr detectors can be scaled to multi-ton and are the most powerful background-free technique for the ultimated experiment in dark matter search (neutrino floor)
- ◆ DS-20k development underway
- ◆ Future plans from DS-20k to ARGO (April 27 LOI to LNGS)

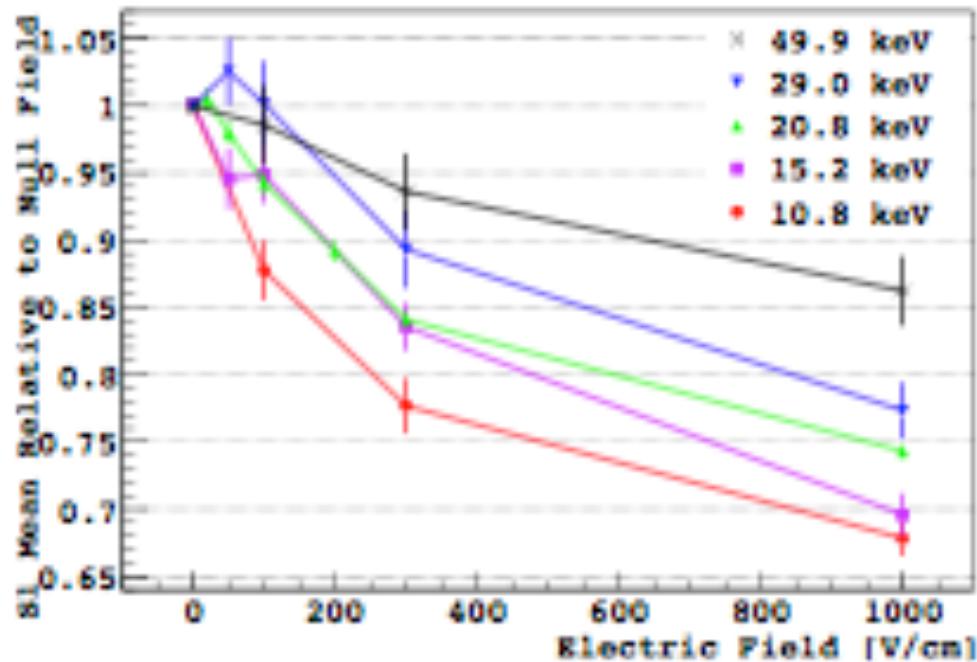
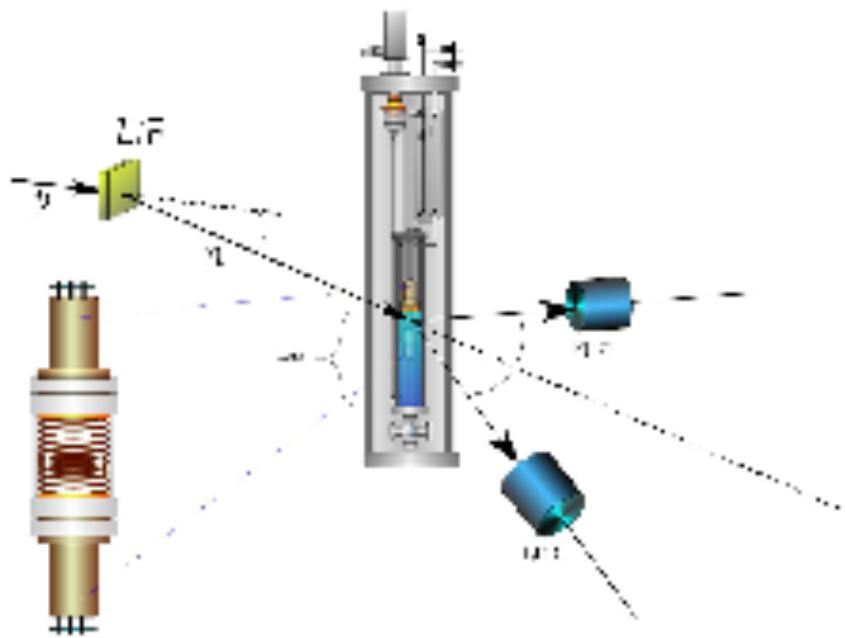
Extra Slides



DS-50 TPC Calibration: SCENE

SCENE

Scintillation Efficiency of Nuclear Recoils in Noble Elements



- LAr TPC exposed to bunched low energy neutron beam
- Extremely pure sample of single nuclear recoils
- Extrapolate NR energy scale and F90 response from SCENE to DS50

Borated Liquid Scintillator

- High neutron capture cross section on boron allows for compact veto size
- Capture results in 1.47 MeV α -particle - detected with high efficiency
- Short capture time (2.3 μ s) reduces dead time loss
- LY of about 0.5 phel/keV_{ee}

	Veto Efficiency (MC)	NIM A 644, 18 (2011)
Radiogenic Neutrons	> 99% (Based on 60 μ s veto window)	
Cosmogenic Neutrons	> 95%	

Liquid Scintillator Veto reconstitution

- Removing high-14C TMB (June, 2014)
Re-distill PC, restore PPO (Dec 2014, Feb 2015)
- Add radio-pure TMB at 5 % concentration (Jan 2015)
- 14C activity decreased from 150 kBq to 0.3 kBq

